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Syllable Rate Determines Functional MRI Response Magnitude During a Speech Discrimination Task

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Introduction

Stimulus rate is a significant determinant of regional cerebral blood flow [1] and of FMRI response [2] in the visual cortex. The following study measured FMRI responses in auditory cortex during a phoneme discrimination task in which the rate of stimulus presentation was varied systematically. Our previous studies demonstrated bilateral superior temporal gyrus (STG) FMRI responses during passive exposure to relatively long speech stimuli [3]. The present work incorporated briefer stimuli permitting faster and more varied presentation rates.

Methods

Five healthy, right-handed subjects were studied using a GE Signa 1.5 T scanner equipped with three-axis local gradient and whole-brain rf coils. FMRI used a gradient-echo EPI sequence (TE = 40 ms, TR = 3 s, FOV = 24 cm). Image matrix was 64 x 64 and slice thickness 10 mm. Sagittal images of the right and left lateral convexity were obtained, centered 13 mm medial to the lateral temporal surface and including temporal, frontal and parietal cortex. Auditory stimuli consisted of digitized human speech, presented using a computer playback system. Sound was delivered by air conduction through plastic tubes inserted in the ear. Each EPI series included 10 periods of "activation," each 18 s in duration. Five EPI series (a total of 50 activations) were obtained during a single 35 min session.

Stimuli were consonant-vowel syllables edited to 400 ms and presented in random order using five different syllable rate conditions: 0.17, 0.5, 1.0, 1.67, or 2.5 Hz. Rate conditions remained constant for the duration of each 18-s activation cycle, but varied randomly from cycle to cycle. Ten activations were imaged in each condition.

To ensure that stimuli were attended in all conditions, subjects performed a phoneme discrimination task requiring a left finger movement response to any occurrence of /b/ or /d/. Target phonemes appeared 2-3 times during each 18-s activation, regardless of the rate condition. Detection indices (d´) were calculated from hit and false positive ratios in each of the five conditions.

Active pixels were identified using an automated analysis program that computed for every pixel the percent change in signal during the 2.5 Hz (fastest rate) stimulus periods. For each activation period, a local baseline was computed by averaging the data values that immediately preceded and followed the activation. Activation measurements were then made by computing the percent change difference between this baseline and the signals obtained during the last half of each 18-s activation period. ANOVA was used to test for rate effects. Means and 95% confidence intervals in each rate condition were calculated for each temporal lobe using normalized percent change measurements combined across pixels and across subjects.

Results

Scores on the discrimination task showed high levels of accuracy (d' $\geq$ 3.4) at all presentation rates. The strongest FMRI changes were observed in the superior temporal lobe bilaterally in all subjects. Differences in FMRI response magnitude during different rate conditions were apparent on visual inspection of time-series data (Fig. 1). Repeated measures ANOVA confirmed a strong dependence of signal change on stimulus rate. Rate effects were highly significant ($F (4, 15236) = 1516$; $p < .00001$) and accounted for 92.3% of the explained variance.

Active pixels were located in transverse temporal gyri (primary auditory cortex), on the lateral surface of the STG, in the planum polare, and occasionally in the planum temporale or superior temporal sulcus. All of these pixels showed positive monotonic, non-linear relationships between stimulus rate and response magnitude over the range of rates studied. An asymptotic effect was apparent at faster rates. Fig. 2 illustrates average rate-response functions of the left and right temporal lobes, generated by combining normalized data from all subjects. Temporal lobe response functions were nearly identical in the two hemispheres.

Conclusions

FMRI signal changes in auditory cortex are dependent on syllable presentation rate. These findings are in accord with those obtained in the visual system using PET and FMRI techniques [1,2], with some differences. The positive phase of the rate-response curve in visual cortex has been described as linear, while our data show a non-linear decay at higher rates. Another feature of previous studies was the finding of a nonmonotonic (positive-then-negative) effect of increasing rate [1,2]. The more restricted range of rates available using speech stimuli may have precluded observation of such an effect in our study.

In contrast to the study by Price et al. [5], we observed no temporal lobe areas that were free of rate effects. This could be due to the "nonsense" nature of our stimuli, or to other unknown factors.

The findings reported here may prove useful as an initial guide in future investigations using auditory FMRI. As a general rule regarding speech stimuli, it is advisable to use syllable rates of at least 1.5 Hz to assure optimal stimulation of the superior temporal auditory cortex.

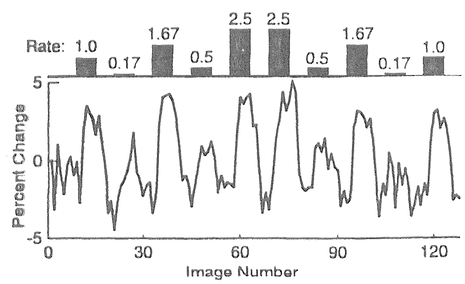
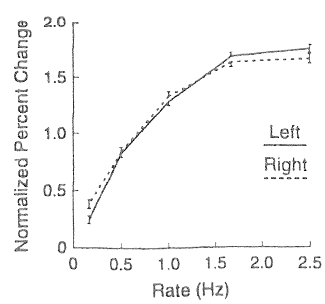


Figure 1. Sample data from one voxel showing percent change at 5 syllable presentation rates.

Figure 2. Mean left and right temporal lobe rate-response functions for five subjects. Error bars = 95% C.I.



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